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ANALYZING THORNDIKE'S LAW OF EFFECT: THE QUESTION OF STIMULUS–RESPONSE BONDS

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The stimulus–response bond postulated by Thorndike's (1911) law of effect is not required in a functional account of behavior in relation to its consequences. Moreover, the notion of a bond has been challenged by the findings of several experiments. Nevertheless, it remains viable in the light of reanalyses of those findings. Thorndike's suggestion that the strength of the bond depends on the magnitude of satisfaction is consistent with current research on resistance to change.

Key words: law of effect, S-R bond, reinforcer devaluation, resistance to change

> Of several responses made to the same situation, those which are accompanied or closely followed by satisfaction to the animal will, other things being equal, be more firmly connected with the situation, so that, when it recurs, they will be more likely to recur; . . . The greater the satisfaction . . . , the greater the strengthening . . . of the bond. (Thorndike, 1911, p. 244)

Although Thorndike's law of effect is cited in virtually all textbooks of learning and conditioning, it is usually the empirical or functional aspect of the law that is emphasized. For example, Chance (1994) states that "Another way of saying the same thing is 'Behavior is a function of its consequences' " (p. 104). Here, I want to concentrate on some theoretical aspects of Thorndike's law, and will address only its positive side, which is quoted above (the omissions refer to discomfort and weakening of the bond).

As described in some of the accompanying papers, one of Thorndike's experiments involved a cat in a puzzle box, where pulling a wire loop was followed by escape from the box and access to food. Over a series of trials, the frequency of ineffective responses, such as clawing at the sides of the box, decreased and loop pulling came to occur rapidly and reliably. An empirical way of describing the result, based on a parallel to Darwinian notions of evolution, is that effective behavior was selected by its favorable consequences out of the variety of responses the cat initially made in the box.

Thorndike's theoretical statement of the law explains how this selection process might work. The situation (S) evokes a variety of responses; one response (R) happens to be followed by satisfaction (S^R); the satisfier stamps in a connection or bond between the situation and the response; and as a result, when the same situation is presented, the response is more likely to occur. In diagram form, $S{:}(R \rightarrow S^R) \rightarrow$ [S-R bond] $\rightarrow$ increase in $p(R|S)$. Clearly, the theoretical bond, in brackets, is superfluous for a functional account. If it is deleted, $S{:}(R \rightarrow S^R) \rightarrow$ increase in $p(R|S)$, which simply asserts that the situation sets the occasion for responses to be followed by reinforcers, leading to an increase in response probability.

However, the theoretical bond is important for two reasons. First, it proposes a mechanism for translating the organism's history of reinforcement over previous trials in the experimental situation into an overt response on the next trial. In addition, as stated in the final sentence of the above quotation, the strength of the bond may be a function of that history, including experimental variables that determine satisfaction: [S-R bond] = $f[S{:}(R \rightarrow S^R)]$. The strength of the theoretical bond cannot be inferred from current responding without circularity. Instead, the bond must be evaluated by inference from the effects of some sort of test in which responding is examined under altered conditions.

The most popular tests have involved reinforcer devaluation. In what may be the first such experiment, Elliott (1928) trained two

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groups of hungry rats, one trial per day, in a 14-unit maze. A control group received sunflower seeds in the goal box throughout training; the experimental group received bran mash for the first 9 days and then was switched to sunflower seeds. Bran mash was the more effective reinforcer, in that errors decreased more rapidly over the first 9 days for the experimental group; but after the switch to sunflower seeds on Day 10, this group immediately exhibited an increase in errors to levels greater than those of the control group. Thorndike's law suggests that the experimental group should at least have maintained its preswitch level of performance because the pattern of correct turns in the maze had been stamped in by previous reinforcers; and one could argue that performance should continue to improve at the same rate as the control group. Thus, the increase in errors is evidence against the S-R bond. Mackintosh (1974) reviewed a number of related experiments and concluded that "The implication, then, is that the role of reinforcement in instrumental learning is not to strengthen antecedent responses; reinforcers do not increase the strength of an association between stimulus and response; they are themselves associated with those responses" (p. 216).

There are some more recent within-subject versions of the Elliott (1928) study that support Mackintosh's conclusion (see Williams, 1997). For example, Colwill and Rescorla (1985b) trained rats to press a lever for food pellets and to pull a chain for liquid sucrose on identical variable-interval schedules in successive sessions (for half the subjects, these contingencies were reversed). They then removed the manipulanda and devalued one reinforcer by delivering it according to a variable-time schedule, paired with illness-inducing lithium chloride (LiCl) injections; the other reinforcer was presented similarly, in alternated sessions, but was not paired with LiCl. During a subsequent 20-min extinction test session, both manipulanda were concurrently available, and there was significantly less responding on the manipulandum whose reinforcer had been devalued than on the alternative. This response-specific devaluation effect appears to be inconsistent with expectations based on S-R bonds, which should have been equally strong for the two responses before one of the reinforcers was paired with LiCl. Instead, the result suggests that each response had been associated with its particular reinforcer.

As shown in Figure 1, responses were not entirely eliminated after their reinforcers had been devalued, even though the subjects did not consume the devalued reinforcers during a separate test. In a later study, Colwill and Rescorla (1985a, Experiment 3) showed that the rate of this "residual" responding was greater than that observed after response-independent reinforcer presentation. Therefore, this residual responding depends on the history of response-dependent reinforcement before reinforcer devaluation—in Thorndike's terms, the S-R bond. Presumably, the S-R bond would be stronger for whichever reinforcer gave greater satisfaction.

There is some evidence in the Colwill and Rescorla (1985b) data that sucrose was more satisfying than pellets. At the end of training, sucrose reinforcers maintained a slightly (but not significantly) higher rate of responding, and during extinction, there was significantly more responding on the manipulandum that produced sucrose during training when it had not been paired with LiCl (see Figure 1). If sucrose was in fact more satisfying than pellets, and thereby established a stronger S-R bond between the experimental situation and sucrose-reinforced responding, then after these reinforcers had been paired with LiCl, the response that had been reinforced with sucrose during training should be more resistant to extinction than the response that had been reinforced with pellets. Colwill and Rescorla's (1985b) data are consistent with this expectation. As shown in the right panel of Figure 1, the level of responding after sucrose was devalued, relative to the group for which sucrose had not been devalued, was consistently greater than for pellets. Thus, at least some aspects of their data provide evidence for S-R bonds that differ in strength.

Length of training is another variable that should affect the strength of the S-R bond. In two related experiments, Colwill and Rescorla (1985a) examined the effects of extended training in several ways—for example, by training the lever press for one session and the chain pull for 13 sessions with the same reinforcer, while a nose-poke response received 14 sessions of training with a different

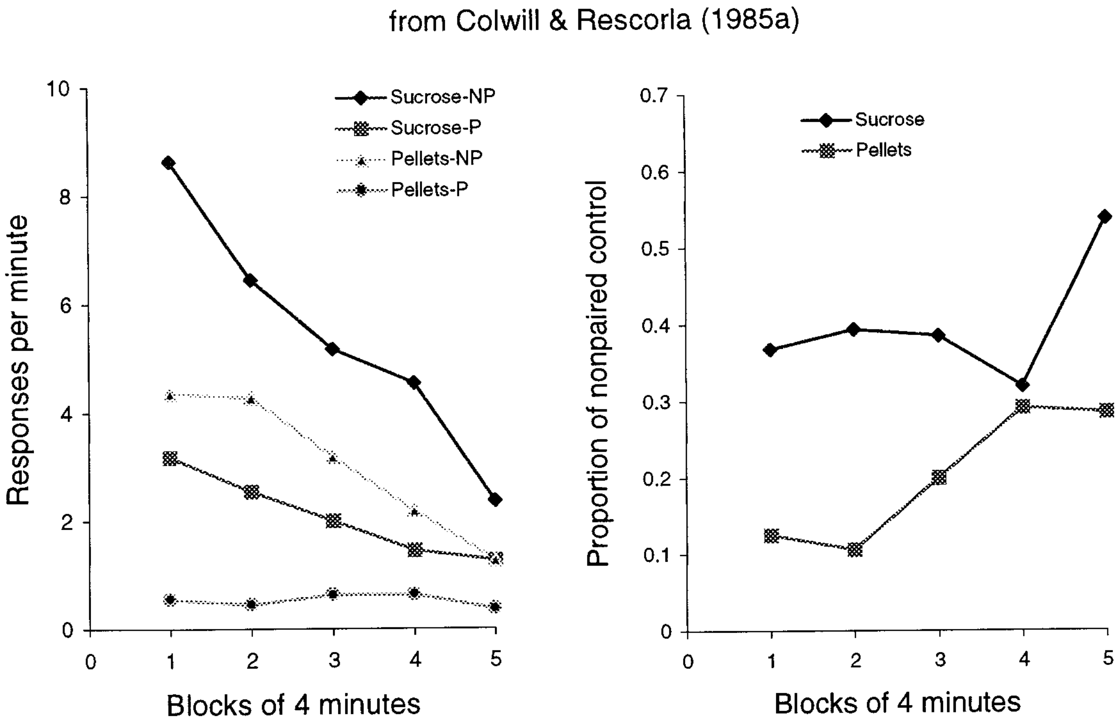

Fig. 1. In the left panel, data from Colwill and Rescorla (1985b, Experiment 1) are replotted to show response rates during a 20-min extinction session after training with sucrose or pellet reinforcers that had been either paired (P) or not paired (NP) with lithium chloride. The right panel shows the rate of a response previously reinforced by sucrose or pellets after pairing with lithium chloride (functions labeled P in the left panel) relative to nonpaired control response rate (functions labeled NP in the left panel) throughout the course of extinction. Proportions of nonpaired control rates were greater for sucrose than for pellets.

reinforcer. Then, one reinforcer was devalued, either for the target response or for the nose poke. The question, for Colwill and Rescorla, was whether the response-specific devaluation effect would survive extended training; but in relation to the notion of an S-R bond, the question is whether extended training increased residual responding relative to unpaired controls. There was a clear response-specific reinforcer devaluation effect with both one and 13 sessions: Responding based on a devalued reinforcer was consistently lower, during extinction, than responding based on a reinforcer that had not been devalued. At the same time, the magnitude of the devaluation effect, relative to nonpaired controls, decreased with extended training. Both aspects of the results were repeated in a second experiment with four different responses, two reinforcers, two levels of training, and two kinds of tests—choice or only a single response available during extinction. These results, which are summarized in Figure 2, confirm the suggestion that resistance to reinforcer devaluation is related to experimental variables in a way that reflects the strength of an S-R bond.

The findings of Colwill and Rescorla (1985a, 1985b), together with those of Adams and Dickinson (1981), led Dickinson (1994) to suggest that "instrumental training established lever pressing partly as a goal-directed action, mediated by knowledge of the instrumental relation, and partly as an S-R habit, impervious to outcome devaluation" (pp. 51–52). Colwill and Rescorla (1985a) had suggested a similar interpretation. Donahoe (1999) shows how a connectionist model with feedback from conditioned reinforcer-elicited activity (cf. Trapold & Overmier, 1972) can simulate both Dickinson's "goal-directed action" and Thorndike's "S-R habit."

In more empirical terms, training with response-contingent reinforcement both selects

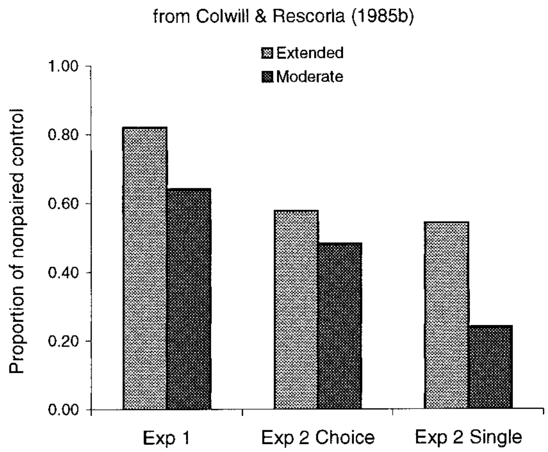

Fig. 2. Data from Colwill and Rescorla (1985a, Experiments 1 and 2) for responding in the first block of extinction after either moderate or extended training with reinforcers that had been either paired or not paired with lithium chloride. The data are expressed as response rates following pairing relative to nonpaired control response rates. In Experiment 1, responses were extinguished singly in successive sessions. In Experiment 2, both responses were available during an initial extinction session (choice), followed by single-response extinction as in Experiment 1. Proportions of nonpaired control rates were greater following extended training.

the response and, separately, makes responding more resistant to change in the training situation (for a review of research on resistance to change, see Nevin, 1992; for discussion in relation to the law of effect, see Nevin & Grace, in press). Response-specific reinforcer devaluation both reflects the current reinforcer value and tests resistance to change based on the predevaluation history of reinforcement. In Thorndike's terms, resistance to change reflects the strength of the S-R bond.

As described above, Thorndike's law of effect links the selective effects of reinforcement to the strengthening of an S-R bond. Subsequent analyses suggest that these processes are separable, not that Thorndike was wrong to invoke the S-R bond as a way to capture what happens during learning.

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